Precise Post-processing of GPS Data: Products and Services from JPL

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BIOGRAPHY

Since joining JPL in 1990, *James Zumberge* has contributed to the development of techniques for efficient and precise analysis of large volumes of GPS data. He received his Ph.D in Physics from the California Institute of Technology in 1981, and is currently Deputy Manager of JPL's Tracking Systems and Applications Section.

Frank Webb received his Ph.D in Geology from the California Institute of Technology in 1991. He began work at JPL in 1990 as a Member of the Technical Staff in the Satellite Geodesy and Geodynamics Systems Group. He is currently the Supervisor of this group whose work is focused on precise orbit determination of the GPS satellites and on the application of GPS to understanding the geodynamics of the Earth.

ABSTRACT

During the 1990s, networks of permanently operating geodetic quality GPS receivers have emerged with spatial scales ranging from kilometers to the global network of the International GPS Service. As a by-product of our intrinsic interest in analysis of data from these networks, JPL offers, by way of anonymous ftp, estimates of GPS clocks and orbits with various latencies and accuracies. These products can be used to facilitate precise post-processing of GPS data from stationary and moving GPS receivers. In addition, a completely automated service, called "ag", uses an e-mail and anonymous ftp interface to allow precise analysis of dual frequency GPS data from stationary receivers. This service obviates the need for a user to learn the details of GPS processing software, and is available to anyone with Internet access. Few-millimeter horizontal and centimeter vertical accuracies are routinely achieved.

INTRODUCTION

Give outline of the paper.

THE GLOBAL NETWORK OR PERMANENTLY OPERATING GPS RECEIVERS

Will mention International GPS Service, show map, describe receivers. Reference Neilan ION paper.

IGS Stations

Figure 1.

Properties of Receivers

Show table of receivers. Describe properties of receivers.

ANALYSIS OF GPS DATA AT JPL

Philosophy of data processing. Reference Zumberge JGR article.

Global Analysis

Describe real-time, rapid, and Flinn, with trade-off between accuracy and latency. Reference Muellerschoen and Jefferson articles.

Regional Analysis

Describe how networks like SCIGN and CORS can be easily handled with our philosophy.

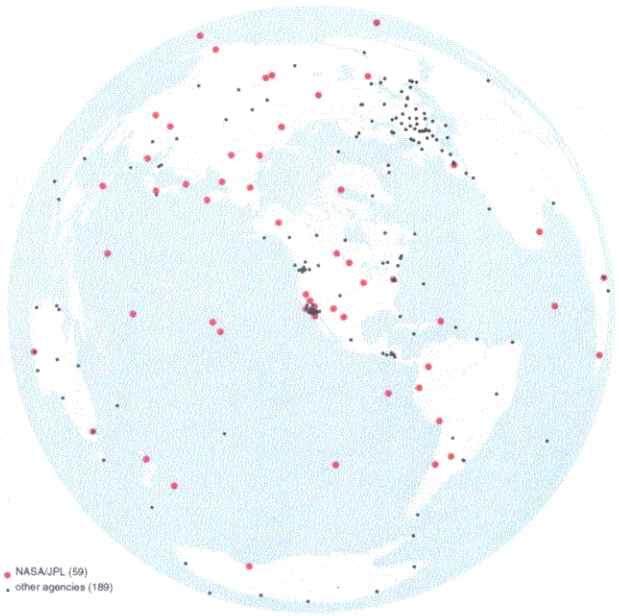

Fig. 1 GPS Tracking Sites in the International GPS Service as of December, 2000

AUTOMATED ANALYSIS SERVICE

Mention availability of GIPSY/OASIS-II.

User can learn GIPSY and analyze own data (using JPL-derived precise transmitter products). Reference: GPS Solutions article.

Alternatively, can send data to JPL for automated analysis there.

Describe how to initiate a request.

Describe what happens on JPL's computer.

Describe what results that user can access.

Figures 2 and 3.

Enhancements.

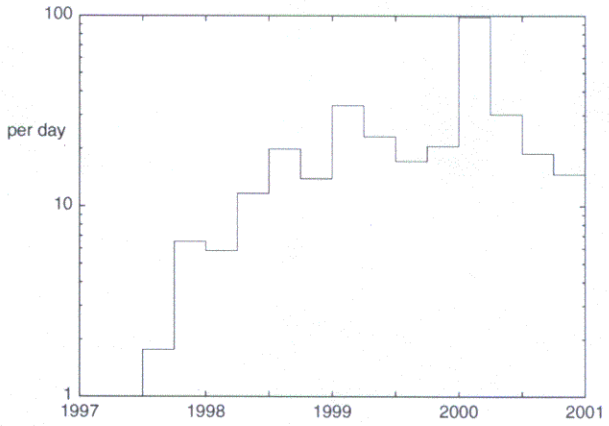

Fig. 2 Rate of Requests Service by AutoGipsy Since Inception

Enhancements

Several enhancements to the system have been considered since it went into operation. To avoid the two-week wait for the Flinn transmitter parameters, it is possible that JPL's rapid service and/or real-time transmitter products could be used when the user's data are less than two weeks old. In this case, data as new as just a few minutes could be analyzed with only slightly less accurate results. A second enhancement would allow kinematic analysis of GPS data, from moving vehicles, for example. In this case, data rates more frequent than once every 30 seconds could be analyzed, and the high-rate clock solutions produced at JPL would be used. Finally, the benefits of phase ambiguity resolution could be realized when analyzing data from a local network of GPS receivers. All of these enhancements are feasible and depend only on sufficient resources for their implementation.

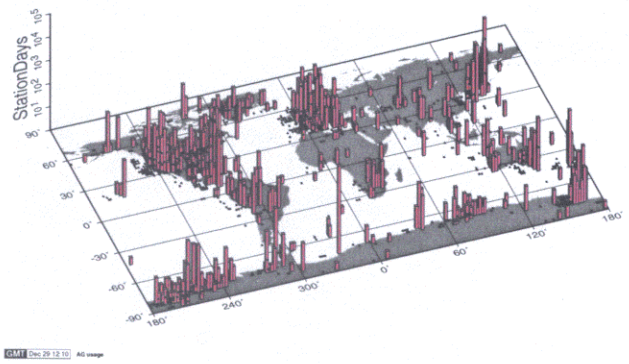

Fig. 3 Geographic Distribution of ag requests (from `http://milhouse.jpl.nasa.gov/ag/`).

Limitations

The ag system was developed to serve science investigators in NASA's Solid Earth and Natural Hazards program. There is currently no charge for the service, although this policy may evolve.

SUMMARY

Short summary.

ACKNOWLEDGMENTS

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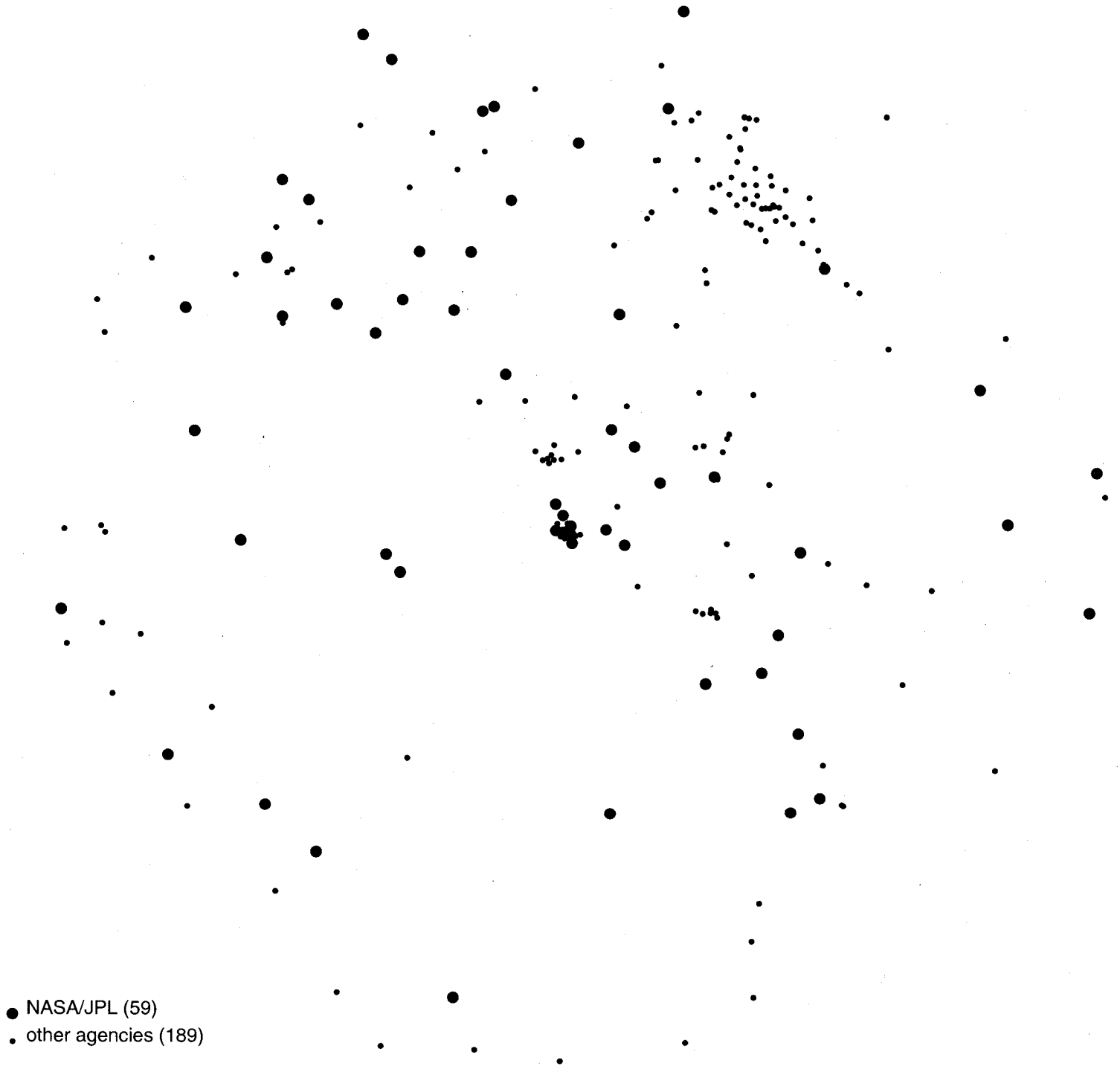
Outline

- the global network of permanently operating receivers
  - the International GPS Service (IGS)
  - properties of receivers
- JPL GPS data processing
  - philosophy
  - global analyses
  - regional analyses
- automated service *ag* using anonymous ftp and e-mail



Locations of IGS Receivers

Kinds of Receivers in the IGS

receiver	*number*
ASHTECH Z-XII3	81
ASHTECH UZ-12	3
ASHTECH Z18	1
AOA SNR-8000 ACT	17
AOA ICS-4000Z ACT	12
AOA SNR-12 ACT	12
AOA BENCHMARK ACT	9
AOA SNR-8100 ACT	6
ROGUE SNR-8000	47
ROGUE SNR-8100	9
ROGUE SNR-12 RM	8
ROGUE SNR-800	1
TRIMBLE 4000SSI	33
TRIMBLE 4000SSE	5
TRIMBLE 4700	2
JPS LEGACY	1
LEICA SR9500	1

Properties of Receivers in the IGS

- rate
  - nominal rate is 30 seconds
  - subset of the network operates at 1 sec
- latency
  - nominal latency is 1 day
  - subset of the network delivers hourly data
  - another subset operates at few-second latency
- dual-frequency and geodetic-quality measurements
- publicly available in Rinex format

Data Processing Philosophy at JPL

- if transmitter (GPS satellite) positions and clock corrections are known, then receiver phase and pseudorange measurements can be used to estimate receiver coordinates and time

- use explicit estimation of clock parameters (as opposed to elimination of clocks through double difference data types)

- transmitter parameters as broadcast are accurate to the level of a couple of meters

- can determine these much more accurately – cm level – by analyzing data from a global network (for example, that of the IGS)

Data Processing Philosophy, continued

- once transmitter parameters are known accurately, can process data from any receiver with high precision and efficiency

GPS phase L and pseudorange P observables

$$L_r^x = \rho_r^x + b_r^x + z_r^x + \omega_r^x + C_r - c^x + \nu_r^x,$$
$$P_r^x = \rho_r^x + z_r^x + C_r - c^x + \eta_r^x,$$

- L_r^x (P_r^x) is measured phase (pseudorange) between transmitter x and receiver r
- ρ_r^x is range
- b_r^x is phase bias
- z_r^x is troposphere delay
- ω_r^x is phase windup
- C_r is receiver clock
- c^x is transmitter clock
- ν_r^x (η_r^x) is phase (pseudorange) noise

Estimated Parameters

- GPS satellite parameters
  - satellite CM motion
  - satellite orientation (when in shadow)
  - satellite clock
- receiver parameters
  - receiver coordinates
  - receiver clock
  - troposphere delay
- phase ambiguity parameters
- Earth orientation

Data Analysis at JPL

- global
  - real-time
  - rapid – 1-day latency
  - "IGS Final" – 1-week latency
- regional – fix GPS satellite orbits and clocks (and Earth orientation)
  - all IGS sites
  - US CORS network
  - SCIGN

JPL Flinn Analysis

`ftp://sideshow.jpl.nasa.gov/pub/`

- `jpligsac/1092/` contains IGS-formatted files for GPS week 1092; links to information on file formats available at `http://igscb.jpl.nasa.go`
  - `jpl10923.clk.Z` contains satellite and station clocks
  - `jpl10923.tro.Z` contains troposphere estimates
  - `jpl10923.sp3.Z` contains satellite orbits
  - `jpl10923.yaw.Z` contains satellite yaw rates
- `gipsy_products/2000/` contains GIPSY-formatted files for year 2000

Automated Analysis Service: *ag*

- user can
  - fetch precise transmitter parameters
  - use these and his own software to analyze his own data
- *or*
  - send his data to computer at JPL
  - receive results of analysis

How to use *ag*

- format your dual-frequency data into a Rinex file, and name the file according to the Rinex convention

- place the file in an area which can be accessed by anonymous ftp

- send an email to `ag@cobra.jpl.nasa.gov`
  - the subject field should be `Static`
  - the body should contain the URL of the file to be analyzed

- receive results of analysis
  - e-mail from `ag`
  - body contains URL of analysis results

How to use *ag*, continued

⇒ Initiate a request (Unix):

```
% echo ftp://mypc.univ.edu/pub/toul1800.97o \
| mailx -s"Static" ag@cobra.jpl.nasa.gov
```

⇒ E-mail response from ag:

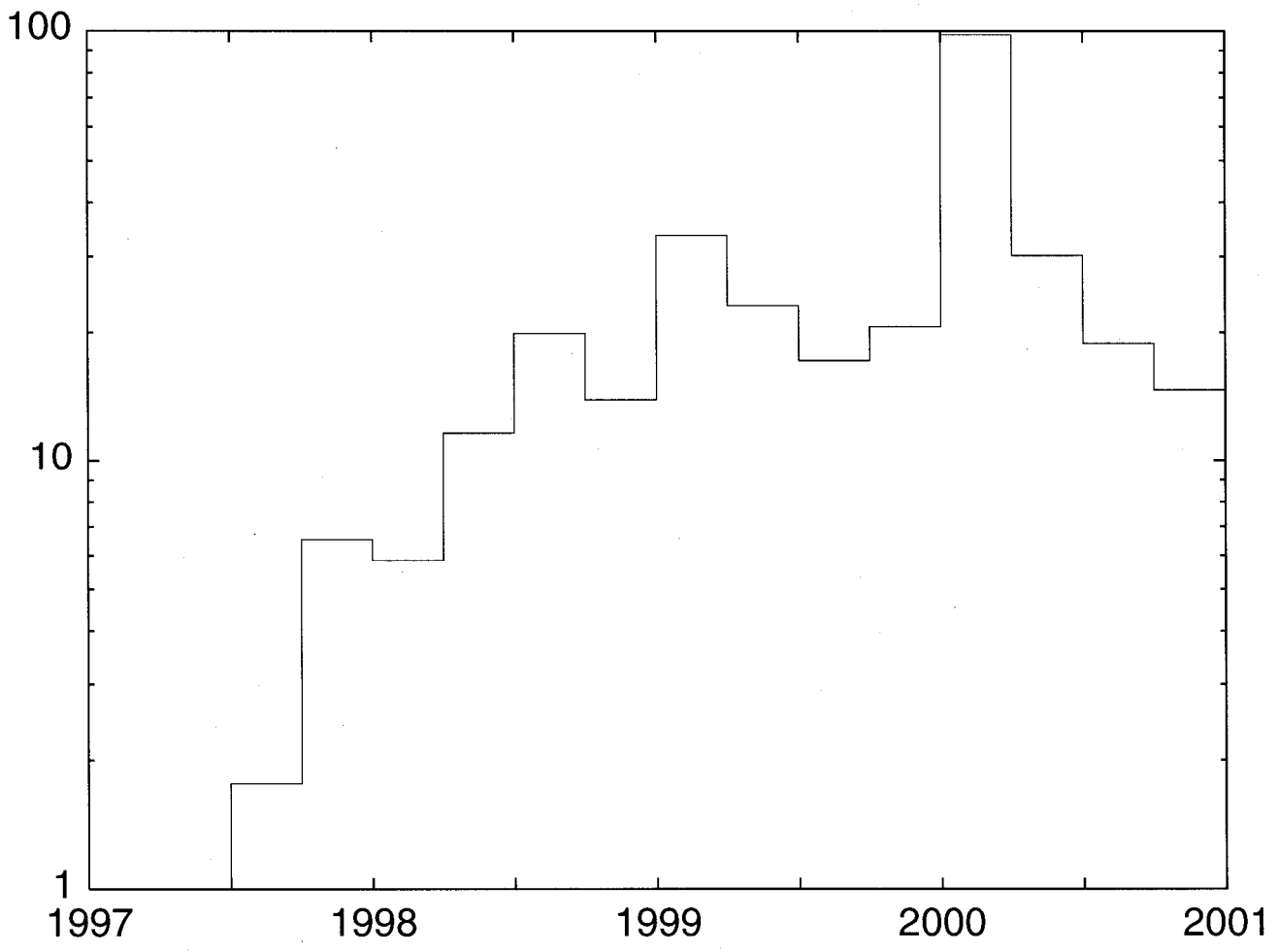
> You can find several files in directory
>
> ftp://sideshow.jpl.nasa.gov/pub/ag/2000.12.29.13.00.5
>
> They will disappear within a few days.

⇒ Output files:

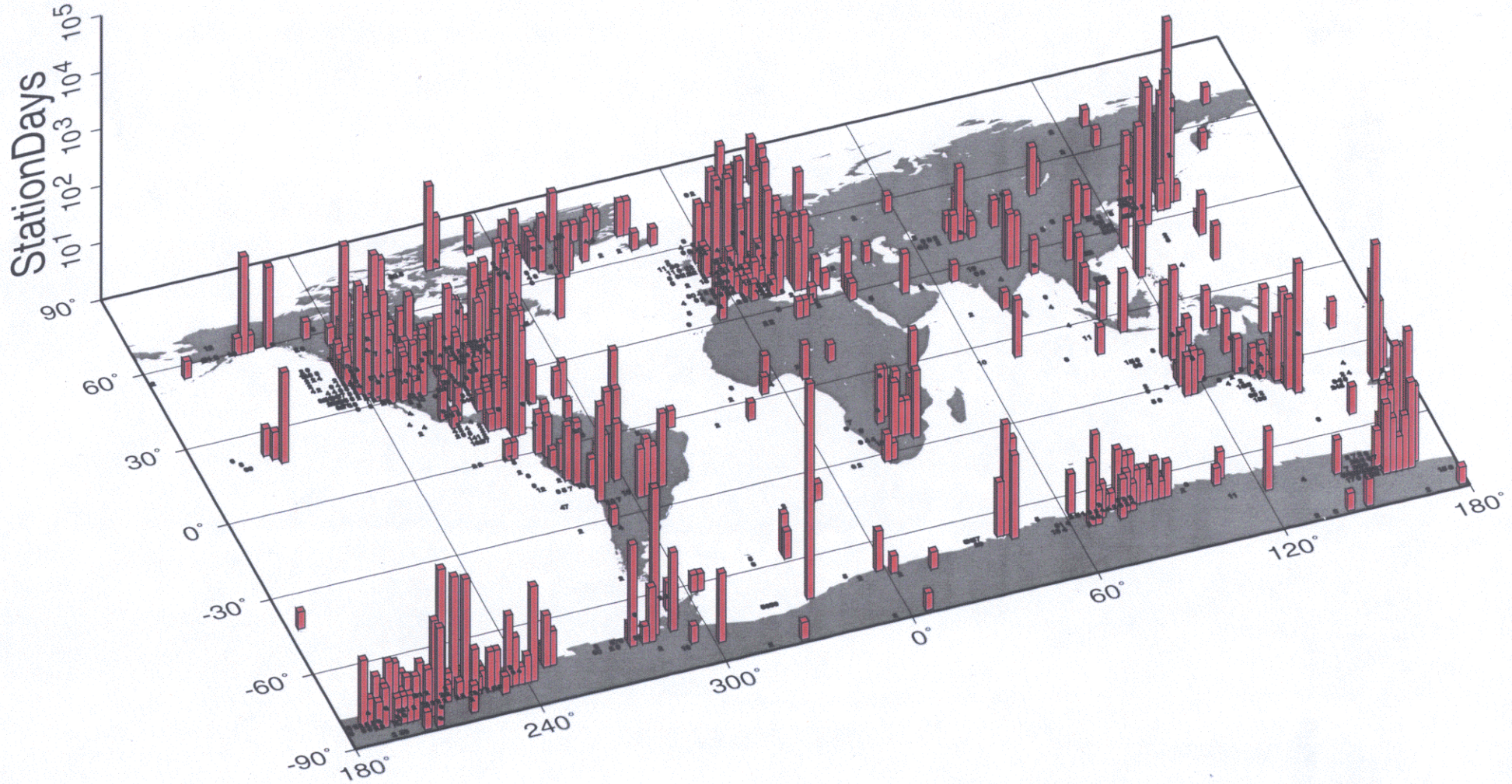
1997-06-29.TOUL.gd.Z	geodetic coordinate
1997-06-29.TOUL.pfr.Z	post-fit residual
1997-06-29.TOUL.rgnml.Z	Gipsy-specific input fil
1997-06-29.TOUL.stacov.Z	free-network Cartesian coordinate
1997-06-29.TOUL.stacvx.Z	ITRF Cartesian coordinate
1997-06-29.TOUL.tdp.Z	clock and troposphere
LOG	one-line numeric summar
README	explanatio

Demand for ag

number of requests logged per day



AG Usage since Oct. 1998



GMT Dec 29 12:10 AG usage

Enhancements

- kinematic option for moving platforms
- more rapid determination at JPL of transmitter parameters
- ambiguity resolution